International Journal of Environment and Climate Change

Volume 13, Issue 11, Page 4408-4417, 2023; Article no.IJECC.109593
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

The Effect of Climate Change on Wheat Production: Present Patterns and Upcoming Difficulties

Ajeet Kumar Gupta [a++], Mohit Agrawal [b#], Abhinav Yadav [a++], Harikant Yadav [c++], Govind Mishra [a++], Rishabh Gupta [a++], Abhay Singh [a#], Jay Singh [d++*] and Piyusha Singh [a†]

[a] Department Genetics and Plant Breeding, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh (224229), India.
[b] Department of Genetics and Plant Breeding, Chaudhary Charan Singh University, Meerut (250001), Uttar Pradesh, India.
[c] Department of Genetics and Plant Breeding, G. B. Pant University of Agriculture and Technology, Pantnagar (263145), Uttrakhand, India.
[d] Department of Seed Science and Technology, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, (208002), India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2023/v13i113621

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/109593

Minireview Article

Received: 22/09/2023
Accepted: 30/11/2023
Published: 06/12/2023

ABSTRACT

Climate refers to the mean weather conditions in a certain region, impacting every aspect of the environment. Urbanisation and industrialization are causing woods to be cleared for living communities. The equilibrium of the ecosystem is upset by this shift, affecting producers,

++ *Research Scholar;*
# *M. Sc. (Ag);*
† *Assistant Professor;*
**Corresponding author: E-mail: singhjay57346@gmail.com;*

consumers, and decomposers. Plants, or producers, are an important component of the ecosystem because they supply energy. Plant sustainability and production are impacted by this change. A staple grain, wheat is greatly impacted by both temperature and CO2 levels. In addition to decreasing wheat productivity, it also increases wheat's susceptibility to many illnesses. Elevated temperatures result in increased transpiration, which in turn triggers drought, which in turn causes reduced production. According to predictions, in the next 20 to 30 years, a 2° C temperature shift might result in a serious water crisis. A scarcity of water during the grain filling and milking stages can impact production. This article covers the following topics: climate-related variables, effects on wheat production and growth, influence on disease severity, temperature increase prediction model, and CO2 curve in 2050.

Keywords: Ecosystem; drought; productivity; warming.

1. INTRODUCTION

Both natural and man-made causes have an impact on long-term weather pattern changes. Daily changes in the climate are caused by both human activity and a number of natural factors. The buildup of carbon dioxide in our atmosphere is a major contributor to climate change. Burning fossil fuels, vehicle emissions, the production of chlorofluorocarbons from electric appliances (such as air conditioners and refrigerators), and volcanic eruptions all contribute to the buildup of carbon dioxide in the atmosphere. When we breathe, humans emit carbon dioxide into the atmosphere. Since carbon dioxide is one of the most significant greenhouse gases, its accumulation in the atmosphere intensified the greenhouse effect. It has been noted that the amount of carbon in the atmosphere has increased by 80% since the beginning of life on Earth. Humans are the primary cause of its enhanced worth. Plants used released carbon in the past since it is the primary component of photosynthesis. Nonetheless, as time goes on, more people become homeless and use agricultural land for housing. As colonisation spread, deforestation began, and cultivated or agricultural land was converted into housing communities. The air becomes thick with carbon dioxide emitted by cars [1]. Methane, nitrous oxide, ozone, water vapour, and halocarbons are some of the other gases. These gases form a sheet surrounding the planet. Because of the intense cold, this layer is denser in the northern hemisphere, where people consume more fossil fuels. This layer of gases raises the temperature of the Earth, which is referred to as global warming. These two concepts are linked. This temperature rise impacts not just humans, but also all natural habitats and ecosystems on the planet. Climate change affects humans, plants, animals, and microorganisms not just outside, but also inwardly by disrupting their DNA and triggering mutation, resulting in irreversible change on a species level. Many animal and plant species are threatened as a result. This disrupts the life cycle of insects, increases disease resistance, and causes cultivars to underperform, all of which contribute to problems with food security.

90% of wheat is grown in dry and semi-arid settings with irrigation. Climate change particularly affects wheat in rainfed regions. Australia and Mexico experience 2.85 billion dollars' worth of wheat loss annually due to climate change impacts on wheat productivity [2].

By 2050, food demand is predicted to quadruple, while production yields will decline as a result of rising carbon dioxide concentrations and global warming. The effects of global warming on plants, infections, insects, and pests are mostly detrimental [3].

One of the primary areas of wheat production in both India and the world is the Indo-Gangetic Plain (IGP). Changes in temperature, precipitation, and the amount of water available for irrigation will all have an impact on wheat yields in this area as a result of climate change, posing serious questions about the security of the food supply on a global and national scale. Here, we employ both a crop model and a regional climate model to gain a better understanding of the direct (due to variations in temperature and precipitation) and indirect (due to a reduction in irrigation availability) effects of climate change on wheat yields at four sites located in the Indian Great Plains states of Punjab, Haryana, Uttar Pradesh, and Bihar.The findings indicate that during the growth season, also known as the Rabi season (November–April), there is a rise in the mean temperature, precipitation, and maximum temperature. Depending on the place under investigation, the direct effects of climate change result in losses in wheat production ranging from −1% to −8% due to variations in temperature and precipitation. Next, the indirect effects of climate change are investigated, taking into account how changes in water supply may result in less irrigation. In this scenario, yield losses escalate significantly, ranging from −4% to −36%, contingent on the location under investigation and the irrigation schedule used (6, 5, 3 or 1 irrigations). This study demonstrates that for future wheat yields in the IGP, the indirect effects of climate change may be more harmful than the direct ones. It also highlights how complicated climate risk is and how important it is to take into account indirect effects of climate change in order to properly evaluate how it affects agriculture and select the most appropriate adaptation strategy [4].

2. POTENTIAL CLIMATE CHANGE EFFECT ON SUSTAINABILITY OF CROP

Climate change refers to long-term changes in the environment and is one of the major issues of the twenty-first century. A change in the mean or the variable character of the climate's attributes that lasts for a few decades or longer is referred to as climate change. The two basic natural resources needed for plant growth—water and sun energy—are the basis for food production. Climate change therefore has two potential effects on agricultural production. First off, plant growth, development, and yield are directly impacted by variations in temperature, CO2 levels, rainfall/precipitation, and other factors. Second, a number of variables, including soil organic content, irrigation accessibility, snowmelt, and periodic floods and droughts, may have a big influence on how agricultural land is used. Rainfall determines when to plant and how much water is available. Temperature controls crop development, but length and relative humidity regulate the occurrence of pests and diseases. Radiation affects the productivity of photosynthetic processes. The physiology of standing crops is significantly impacted by wet and dry spells, which leads to output losses. India's agricultural output would be significantly impacted by each of these events. The influence of climate change on India's sustainable agricultural production is the main topic of this chapter [5].

3. EFFECT OF CLIMATE CHANGE ON WHEAT GROWTH AND PRODUCTION

Crop productivity is affected differently by climate change. A 1°C rise in temperature is thought to be responsible for a 10–20% drop in crop output worldwide. In a similar vein, a rise in temperature of 1 to 3 °C is predicted to minimise yield decline in potato harvests by 20–30% [6]. This effect might get worse because it is predicted that temperatures would rise by 2-4°C by the end of the century, which will have an impact on agricultural productivity [7]. Extreme climatic shifts brought about by weather conditions eventually have a lasting impact on agriculture worldwide [8]. Future wheat output in Australia is highly dependent on heat stress; multiple studies are conducted globally to measure yield risk in relation to heat, rainfall, and drought conditions, as well as various cropping types [9]. In Europe, early maturity protects wheat against the effects of drought. Low rainfall and high temperatures are associated with drought, but it is somewhat controllable [10].

Numerous studies have shown that agricultural output is directly predicted by climate change. Temperature increases of one degree cause the growth characteristics and yield to decline. A significant shift in the growth season's temperature was documented. Based on data spanning 100 years, they forecast a 100-year crop model for variations in global climate (temperature and rainfall) and their impact on wheat output [11]. Dry weather has a significant impact on blooming time in the northern regions of Europe, which results in significant yield reductions [12]. The yield of wheat under this scenario of climate change through 2050 and its consequences have a detrimental effect on wheat output. The basis for all research on wheat productivity was global warming and temperature rise using several global climate change models. Hernandez-Ochoa et al. [13] investigated the relationship between temperature and changes in rainfall patterns and carbon dioxide levels. Five global climate models, two ensembles with two scaling strategies, and quantified uncertainty were employed by the researchers. High temperatures and high carbon dioxide concentrations were associated with yield loss, as seen by the spatial and temporal variability at the several research locations. Other investigations yielded similar results [14].

Production is lowered during high temperature spikes, and spikes become more susceptible to illness stress. A temperature higher than 32°C during anthesis reduces the size of the grain and shortens the time the grain fills the spikes, both of which have an impact on wheat output [14]. In regions where wheat is rainfed, variations in rainfall patterns have a greater impact on wheat production; yields decrease by 5-7 percent for every degree of temperature increase [15]. According to Asseng *et al*.'s [16] count in Sudan, a 6 percent yield loss occurs when the temperature rises from 27°C to 13°C.

For C3 plants, elevated carbon dioxide levels are advantageous because they boost biomass output, stomatal conductance, metabolism, and photosynthetic rate. A higher temperature alters how carbon and nitrogen are absorbed by grains and reduces their nutritious value [17]. When plant growth and productivity are impacted by drought, precipitation, and reduced humidity, the situation becomes even worse [18].

4. CLIMATE CHANGE AND DISEASES ATTACK

The population of pathogens is strongly impacted by climate change. Water and temperature are crucial for the genesis and survival of infections. The air temperature in Germany increased by 0.8–1.1°C between 1900 and 2000, which resulted in a rise in winter rainfall. In the end, this suited the pathogen life cycle, allowing it to colonise agricultural detritus and get access to certain vulnerable hosts [19].

In an experiment conducted by Lucas et al. [19], three fungal pathogens—F. culmorum, F. graminearum, and Rhophitulussolani—were used to determine how long the disease pathogens would survive on infected maize leaves. Heating wires were also used to control temperature. After 152 days, microbial biomass and fungal colonisation were noted. DNA was used to report pathogen development, glucosamine was used to evaluate saprotrophic biomass, and muramic acid was tested for bacteria, with the results compared to control values. Furthermore, it was noted that R. solani's DNA drastically dropped whereas F. culmorum's DNA remained unaffected by the soil's increased temperature due to its higher DNA production.

By affecting the geographical and temporal dynamics of disease outbreaks, climate change is projected to have a negative impact on worldwide agricultural productivity. Crop diseases become more severe as a result of physiological changes in plants brought on by rising temperatures and atmospheric carbon dioxide levels. Agro-climatic zone changes brought on by warming may force host plants to move into new regions, which might lead to the formation of new disease complexes. Climate change will have an effect on the global disease scenario because it can influence pathogen development, lead to changes in host-pathogen interactions, and promote the formation of new pathogen races, which in turn undermine host-plant resistance [20].

In the last 200 years, environmental changes brought on by both natural and human activity have increased globally. In the twenty-first century, it is anticipated that the rise in greenhouse gases will continue to raise the world temperature and alter water availability. Environment has a significant impact on plant illnesses; if the environment is not hospitable to the disease, a vulnerable host won't become infected by a virulent pathogen. Each illness may react differently to changes in CO2 concentrations, temperature, and water availability, which can have positive, neutral, or adverse impacts on disease development. The idea of illness optima, however, could be applicable to all pathosystems. Environmental influences have an impact on all plant resistance mechanisms, including pattern-triggered immunity and effector-triggered immunity, RNA interference, and defence hormone networks. Temperature and humidity have an impact on the virulence mechanisms of pathogens, including the generation of toxins and virulence proteins, as well as pathogen reproduction and survival. Due to practical considerations, the majority of molecular studies of plant-pathogen interactions in the lab concentrate on well-known pathosystems and employ a limited number of static environmental circumstances that represent just a small portion of the dynamic interactions between plants, pathogens, and their environments found in nature [21].

5. CLIMATE CHANGE AND INSECT POPULATION

Insects are not immune to the effects of climate change, which influence all aspects of agriculture. Drought conditions and temperature increases cause a decline in plant productivity, which is directly related to global warming. Insect populations that depend on plants for survival are directly impacted by declines in plant populations. Additionally, it had a role in the rise in bug epidemics [22]. Major insects which threaten wheat yield are wheat stem sawfly, and orange blossom wheat midge, which results in losses that reach the level of the economic threshold [23]. Microorganisms, insects, and plants are all significantly impacted by variations in the atmospheric concentration of carbon dioxide. In addition to all management measures, insects and disease pathogens significantly minimise yield losses [16]. Herbivorous insects and diseases are affected by the biochemistry of plants that is altered by global warming [24]. As a result of global warming, several abiotic forces are disrupting insect populations. Due to the rising temperatures, there is an increase in the population of insects, which easily spread viruses from afflicted to healthy plants. Beneficial insects are severely impacted by these climatic changes since they are unable to withstand dry, hot weather and are also less able to eliminate destructive insects. Climate change's negative consequences include rising temperatures and CO2 concentrations, accelerating photosynthesis, and increasing productivity, but it also reduces agricultural output because of shifting weather patterns [25].

Crop output and agricultural pests are significantly impacted by climate change and harsh weather occurrences. Insect pests react to various sources of climate change differently since they are typically adaptive creatures. In this paper, we discuss how changing precipitation patterns, rising temperatures, and atmospheric CO2 levels affect agricultural insect pests. The most significant environmental factor influencing the dynamics of insect populations is temperature, so it is anticipated that rising global temperatures will cause an increase in their geographic range, overwintering survival, number of generations, risk of invasive insect species and plant diseases, and interactions with natural enemies and host plants. Future pest control techniques are desperately needed as the pest problem gets worse due to climate change. These include keeping track of pest numbers and the climate, modifying integrated pest control plans, and using the modelling prediction tools that are discussed here [26].

The biodiversity of insects has been the subject of several prior studies, some of which have focused on reductions while others have shown changes in species composition without net declines [26,27,28,29]. Although studies have demonstrated that changes in biodiversity are predominantly caused by land-use change and increasingly by climate change [30,31] it is yet unknown if these two factors could interact with insect biodiversity on a global scale. Here, we demonstrate how the relationship between historical climate warming indices and intensive agricultural land use is linked to decreases in insect assemblage species counts and abundance of nearly 50% and 27%, respectively, when compared to less disturbed habitats with lower historical climate warming rates. While certain positive responses of biodiversity to climate change occur in non-tropical regions in natural ecosystems, these patterns are more noticeable in the tropical realm. Only in low-intensity agricultural systems does a large supply of adjacent natural habitat frequently offset losses in insect number and richness linked to agricultural land use and significant climate change. Abundance and richness were reduced by 7% and 5%, respectively, in such systems where high levels (75% cover) of natural habitat are present, as opposed to decreases of 63% and 61% in areas where less natural habitat is present (25% cover). Our findings suggest that reducing agricultural intensity, protecting natural habitat in landscapes, and mitigating climate change will likely all increase insect biodiversity [32].

6. PREDICTION MODEL FOR DISEASE ELEVATION IN CORRELATION TO CARBON DIOXIDE

It was 270µmol/mol which was 408µmol/mol in 2017 [33]. Since carbon dioxide is the primary component of photosynthesis, this has an immediate impact on the development and metabolism of plants. However, C3 plants are adversely affected by excessive carbon dioxide, which raises plant biomass and produces the carbon dioxide fertilisation effect. This phenomena is described from several angles within the agricultural ecosystem, although its scope differed from place to place based on temperature, moisture content of the soil, and climatic conditions [34]. In terms of nutrient intake, water availability to the plant, and water reservoirs during the hot and dry season, various locations react to this high CO2 in different ways. Modelling creates a great deal of uncertainty in the crop's reaction to this elevated CO2. Wheat is planted worldwide, and in Mediterranean regions, climatic variables influence the production by over 15% annually. Rainfall is the primary supply of water in Mediterranean regions, which is crucial for wheat plant growth in its early stages. Lack of water availability severely impacts the wheat grain filling stage; this situation is known as a terminal drought and eventually impacts crop production [35]. While this drought encourages wheat to develop a deep root system and decreases stomatal conductance to preserve water, it might be detrimental to the grain during the filling stage. However, if there is more water available, the plant will continue to grow stronger and taller, and if it doesn't reproduce right away, it may die off before grains develop. Additionally, the plant becomes susceptible to disease [36].

7. IMPACT OF CLIMATE CHANGE AND VARIABILITY ON RICE-WHEAT CROPS

Significant drops in crop production have been linked in several Asian regions in recent decades to irregular and severe rainfall patterns, as well as decreased timely availability of water and rainfall [37, 38]. Even with the green revolution's enhanced crop yield, climate change scenarios present significant challenges for maintaining output and enhancing food security for Asia's impoverished rural communities [39, 40]. Damage from climatic shifts may jeopardise national economic production and food security in the least developed nation [41]. Due to differences in climatic trends, yield decreases in various crops (such as wheat and rice) differed among areas [42]. Although it cannot lessen the impacts of rising temperature, CO2 fertilization can boost crop yield and counteract the dramatic consequences of higher temperatures in C3 plants [43,44]. Rising temperatures and unpredictable rainfall have a severe impact on crop growth and development [45,46].

In Asia, rice and wheat play a significant role in ensuring food security. To meet the constantly rising demand for food, it will be extremely difficult to increase wheat production by 60% by 2050 [47]. Reduced crop productivity in arid to semi-arid areas is linked to rising temperatures at lower latitudes. Drought and flooding have decreased the yields of rice, wheat, and maize in China; it is anticipated that these problems will have a greater impact on crop productivity in the future [48]. According to Yang et al. [49], rice is susceptible to a gradual rise in nighttime temperature. If this temperature increase exceeds the threshold temperature of 24°C by 2°C, rice production and biomass would decrease by 16–52%. Asia's semi-arid to dry regions are in danger of becoming much more so, since poor production and drought stress are already issues. The detrimental effects of rising temperatures and intense, irregular rains have resulted in a decrease in the quality of wheat product (protein content, sugars, and starch) as well as grain yield [49]. Climate variability has led to a considerable decline in wheat production in the Egyptian North Nile Delta (up to 17.6%), India, and China. This decrease is linked to rising temperatures, irregular rainfall, and an increase in insect pest infestation [50,51,40,52]. According to Chun et al. [53], rice output in rain-fed parts of South Asia has already declined and might do so again by 14% under the RCP 4.5 scenario and 10% under the RCP 8.5 scenario by 2080. Due to their detrimental effects on the booting and anthesis stage, high temperatures and drought have reduced rice yields throughout Asia, particularly in Pakistan and China [54,55]. Similar to this, heat stress poses a serious risk to rice since it reduces the number of productive tillers, causes grains to shrink, and eventually lowers rice grain output [56]. Rain-fed lowland rice (>13 million hectares) and highland rice (10 m ha) in Asia would be impacted by climate change.Table 1 shows the expected production of wheat and rice crops by 2030.

Table 1. Shock to productivity brought on by climate change and unpredictability in the production of wheat and rice crops by 2030

Countries	Wheat	Rice
China	- 10 to + 14	- 12 to + 12
Phili[pines	- 10 to + 4	- 10 to + 4
Thailand	- 10 to + 4	- 10 to + 4
Rest of the SE Asia	- 10 to + 4	- 10 to + 4
Bangladesh	- 10 to + 4	- 10 to + 4
India	- 10 to + 4	- 15 to + 4
Pakistan	- 10 to + 4	- 15 to + 4
Rest S Asia	- 10 to + 4	- 15 to + 4

Source - Gouldson et al. 2016, Asseng et al. 2019, Chow et al. 2019, Degani et al. 2019, Sanz Cobena et al. 2019, Suryadi 2020 [57,48,58,60,61,62]. Positive (+) sign indicates increase in productivity while minus (-) sign indicates decrease in productivity

8. MANAGEMENT STRATEGIES

Worldwide agriculture productivity is impacted by global warming. Pricey food products are the first indication of an impending global food scarcity, which will worsen quickly if unchecked. Scientists must thus create agricultural seeds that are resistant to the main hazardous factors—drought, salt, and severe diseases. in order to fulfil the population's need, the production of wheat crops must rise. Agronomic techniques such as when to plant, how much water to use, what nutrients are available, when to pull weeds, and the use of resistant cultivars are all examples of adaptive practises. Crops with genetic modifications are valuable instruments for productivity.Compared to the labor-intensive and unreliable conventional breeding approach, it is a simple and rapid procedure. Wheat productivity is increased by molecular breeding to withstand various abiotic and biotic challenges that crops encounter in field cultivation. Molecular markers are useful in determining where different genes are inserted and active. The discovery of new resistance genes and the possibility of their insertion into various crops are made feasible by advances in DNA sequencing [62]. The government ought to implement management plans to reduce global warming. The design of new projects should focus on reducing water loss and using fewer pesticides in agricultural settings. To counteract actions that are altering our ecology, specific public awareness campaigns should be launched. Agricultural land should be irrigated with water that is free of pollutants. Instruments for measuring airborne carbon concentration and temperature monetization should be available. Techniques that are useful in conservation should be practised during training sessions [38].

9. CONCLUSION

Climate changes are caused by an increase in carbon dioxide emissions, which contribute to the global greenhouse effect. These changes have varying effects on all agricultural ecosystems; occasionally, one factor promotes plant growth, but when combined with other factors, the positive effect becomes a sharply negative one. The increasing temperature variations throughout the world and their effects on wheat plant development, biochemistry, grain size and weight, insect pest populations, and microbiological diseases are covered in detail in this chapter. According to a review of the research, C3 plants benefit from a worldwide rise in carbon dioxide because it promotes their development, increases their ability to absorb water, and increases agricultural output. Additionally, when C3 plants are cultivated alongside the main crop, they compete with C4 weeds and strengthen the plants' resistance to disease. However, these advantages become disadvantageous when the temperature rises. Suddenly, plants are unable to absorb nutrients from the soil, which retrains grain size, weight, and crop resilience to illnesses. Additionally, insect populations grow and plant water-holding capacity decreases. Variations in temperature affect the rate of precipitation, which in turn intensifies drought conditions. These factors are critical for wheat cultivation in Mediterranean and rainfed parts of the world. This situation enhances crop and nutrient competition for food and water, favouring C4 weeds over wheat crops. It is also discussed how, if these impacts are not contained, there will likely be a significant food scarcity in the years to come, given that food production is already predicted to double as the world's population grows daily and industrialization raises these hazards. Thus, in order to preserve our environment and ensure that our world is a safe place to live, it is crucial that we put the management strategies recommended in this chapter into practise.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Sadras VO, Calderini DF. Crop physiology: applications for breeding and agronomy. In: Crop Physiology. Academic Press. 2015;1-14.
2. Economics AB. Agricultural commodity statistics; 2018.
3. Alexandratos N, Bruinsma J. World agriculture towards 2030/2050: The revision; 2012.
4. Daloz AS, Rydsaa JH, Hodnebrog Sillmann J, van Oort B, Mohr CW, Agrawal M, Emberson L, Stordal F, Zhang T, 2021. Direct and indirect impacts of climate change on wheat yield in the Indo-Gangetic plain in India, Journal of Agriculture and Food Research. 2021; 4;2666-1543.
5. Atta K, et al. Potential Impacts of Climate Change on the Sustainability of Crop Production: A Case in India. In: Pande, C.B., Moharir, K.N., Negm, A. (eds) Climate Change Impacts in India. Earth and Environmental Sciences Library. Springer, Cham; 2023. Available:https://doi.org/10.1007/978-3-031-42056-6_12.
6. Rose G, Osborne T, Greatrex H & Wheeler T. Impact of progressive global warming on the global scale yield of maize and

Soybean. Climate change. 2016;134(3): 417-428.

7. Rogelj J, Elzen MD, Höhne N, Fransen T, Fekete H, Winkler H, et al. Paris Agreement climate proposals need a boost to keep warming well below 2C. Nature. 2016;534(7609):631-639.
8. Barlow KM, Christy BPO, Leary GJ, Riffkin PA, Nuttall JG. Simulating the impact of extreme heat and frost events on wheat crop production: A review, Field Crops Research. 2015;171:109-119.
9. Lobell DB, Hammer GL, Chenu K, Zheng B, McLean G & Chapman SC. The shifting influence of drought and heat stress for crops in northeast Australia. Global Change Biology, 2015;21(11):4115-4127.
10. Rezaei EE, Siebert S, Huging H, Ewert F. Climate change effect on wheat phenology depends on cultivar change. Sci. Rep. 2018;8:48–91.
DOI: 10.1038/s41598-018-23101-2
11. Wang Y, Wang L, Zhou J, Hu S, Chen H, Xiang J, et al. Research progress on heat stress of rice at flowering stage. Rice Sci. 2019;26:1–10.
DOI: 10.1016/j.rsci.2018.06.009
12. Bodner G, Nakhforoosh A, Kaul HP. Management of crop water under drought: A review, Agronomy for Sustainable Development. 2015:35(2):401-442.
13. Hernandez-Ochoa IM, Asseng S, Kassie BT, Xiong W, Robertson R, Pequeno DNL, Sonder K, Reynolds M, Babar MD, Molero Milan A, Hoogenboom G. Climate change impact on Mexico wheat production. Agric For Meteorol. 2018;263:373–387.
14. Martre P, Wallach D, Asseng S, Ewert F, Jones JW, Rötter RP, et al. Multimodel ensembles of wheat growth: Many models are better than one. Global Change Biology. 2015;21(2):911-925.
15. Liu B, Asseng S Müller C, Ewert F, Elliott J, Lobell DB, et al. Similar estimates of temperature impacts on global wheat yield by three independent methods. Nature Climate Change. 2016;6(12):1130-1136.
16. Asseng S, Ewert F, Martre P, Rötter RP, Lobell DB & Cammarano D, et al. Rising temperatures reduce global wheat production. Nature Climate Change, 2015;5(2):143-147.
17. Trebicki P. Plant viruses threaten crops as climate warms. Australasian Science. 2016;37(4):36-37.
18. Jones RA. Future scenarios for plant virus pathogens as climate change progresses. Advances in Virus Research. 2016;95:87-147.
19. Lukas S, Abbas SJ, Kössler P, Karlovsky P, Potthoff M, Joergensen RG. Fungal plant pathogens on inoculated maize leaves in a simulated soil warming experiment. Applied Soil Ecology. 2018;124:75-82.
20. Hunjan MS, Lore JS. Climate Change: Impact on Plant Pathogens, Diseases, and Their Management. In: Jabran K, Florentine, S., Chauhan, B. (eds) Crop Protection Under Changing Climate. Springer; 2020. Cham.
Available:https://doi.org/10.1007/978-3-030-46111-9_4.
21. Velásquez AC, Castroverde CDM, He SY. Plant-Pathogen Warfare under Changing Climate Conditions. Curr Biol. 2018;21:28 (10):R619-R634.
DOI: 10.1016/j.cub.2018.03.054.
PMID: 29787730;
PMCID: PMC5967643.
22. Westerling AL. Increasing western US forest wildfire activity: Sensitivity to changes in the timing of spring. Philosophical Transactions of the Royal Society B: Biological Sciences. 2016;371 (1696):20150178.
23. Beres BL, Rahmani E, Clarke JM, Grassini P, Pozniak CJ & Geddes CM et al. A systematic review of durum wheat: Enhancing production systems by exploring genotype, environment, and management (G x E x M) synergies. Frontiers in Plant Science. 2020;1665.
24. Yakir DB, Fereres A. The effects of UV radiation on arthropods: A review of recent publications (2010-2015). International Society for Horticultural Science. 2016; 1134:335-342.
25. Asseng S, Cammarano D, Basso B, Chung U, Alderman PD, Sonder K, et al. Hot spots of wheat yield decline with rising temperatures. Global Change Biology. 2017;23(6):2464-2472.
26. Skendžić S, Zovko M, Živković IP, Lešić V, Lemić D. The impact of climate change on agricultural insect pests. Insects 2021;12: 12(5):440.
DOI: 10.3390/insects12050440.
PMID: 34066138; PMCID: PMC8150874.
27. Lister BC & Garcia A. Climate-driven declines in arthropod abundance restructure a rainforest food web. Proc. Natl Acad. Sci. USA. 2018;115:E10397–E10406 .

28. Soroye P, Newbold T, Kerr J. Climate change contributes to widespread declines among bumble bees across continents. Science. 2020;367:685–688.
29. Outhwaite CL, Gregory RD, Chandler RE, Collen B, Isaac NJB. Complex long-term biodiversity change among invertebrates, bryophytes and lichens. Nat. Ecol. Evol. 2020;4:384–392.
30. Newbold T, et al. Global effects of land use on local terrestrial biodiversity. Nature. 2015;520:45–50.
31. Spooner FEB, Pearson RG, Freeman R. Rapid warming is associated with population decline among terrestrial birds and mammals globally. Glob. Change Biol. 2018;24:4521– 4531.
32. Outhwaite CL, McCann P, Newbold T. Agriculture and climate change are reshaping insect biodiversity worldwide. Nature,2022;605:97–102. Available:https://doi.org/10.1038/s41586-022-04644-x.
33. Crossley MS, et al. No net insect abundance and diversity declines across US long term ecological research sites. Nat. Ecol. Evol. 2020;4:1368–1376.
34. Janzen DH, Hallwachs W, To us insectometers, it is clear that insect decline in our Costa Rican tropics is real, so let's be kind to the survivors. Proc. Natl Acad. Sci. USA. 2021;118, e2002546117.
35. Uddin S, Löw M, Parvin S, Fitzgerald G, Bahrami H, Posch ST, et al. Water use and growth responses of dryland wheat grown under elevated [CO2] are associated with root length in deeper, but not upper soil layer. Field Crops Research. 2018;224: 170-181
36. Kimball BA. Crop responses to elevated CO2 and interactions with H2O, N, and temperature. Current Opinion in Plant Biology. 2016;31:36-43.
37. McKenzie FC Williams J. Sustainable food production: Constraints, challenges and choices by 2050. Food Security. 2015;7(2): 221-233.
38. Bahrami H, Kok LJD, Armstrong R, Fitzgerald GJ, Bourgault M & Henty S *et al.* The proportion of nitrate in leaf nitrogen, but not changes in root growth, are associated with decreased grain protein in wheat under elevated [CO2]. Journal of Plant Physiology. 2017;216:44-51.
39. Hussain J, Khaliq T, Ahmad A, Akhter J, and Asseng S. Wheat responses to climate change and its adaptations: a focus on arid and semi-arid environment. Int. J. Environ. Res. 2018;12:117–126. DOI: 10.1007/s41742-018-0074-2
40. Aryal JP, Sapkota TB, Khurana R, Khatri-Chhetri A, and Jat ML. Climate change and agriculture in South Asia: adaptation options in smallholder production systems. Environ. Develop. Sustain. 2019; 20:1–31. DOI: 10.1007/s10668-019-00414-4
41. FAO IFAD, WFP. The State of Food Insecurity in the World: Meeting the 2015 International Hunger Targets: Taking Stock of Uneven Progress. FAO, IFAD and WFP. Rome: FAO; 2015.
42. Ahmad S, Abbas G, Ahmed M, Fatima Z, Anjum MA, Rasul G, et al. Climate warming and management impact on the change of phenology of the rice-wheat cropping system in Punjab, Pakistan. Field Crops Res. 2022;230:46–61. DOI: 10.1016/j.fcr.2018.10.008
43. Myers SS, Smith MR, Guth S, Golden CD, Vaitla B, Mueller ND, et al. Climate change and global food systems: potential impacts on food security and under nutrition. Ann. Rev. Public Health. 2022;38:259–277. DOI: 10.1146/annurev-publhealth-031816-044356
44. Yu H, Zhang Q, Sun P, Song C. Impact of droughts on winter wheat yield in different growth stages during 2001–2016 in Eastern China. Int. J. Disaster Risk Sci. 2018;9:376–391. DOI: 10.1007/s13753-018-0187-4
45. Obermeier WA, Lehnert LW, Kammann, CI, Muller C, Grunhage L, Luterbacher J, et al. Reduced CO2 fertilization effect in temperate C3 grasslands under more extreme weather conditions. Nat. Climate Change. 2017;7:137–148. DOI: 10.1038/nclimate3191
46. Arunrat N, Pumijumnong N, Hatano R. Predicting local-scale impact of climate change on rice yield and soil organic carbon sequestration: a case study in Roi Et Province, Northeast Thailand. Agric. Sys. 2018;164:58–70. DOI: 10.1016/j.agsy.2018.04.001
47. Rezaei EE, Siebert S, Ewert F. Impact of data resolution on heat and drought stress simulated for winter wheat in Germany. European Journal of Agronomy. 2015;65: 69-82.
48. Asseng S, Martre P, Maiorano A, Rotter RP, O'leary GJ, Fitzgerald GJ, et al. Climate change impact and adaptation for

wheat protein. Glob. Change Biol. 2019;64: 155–173.
DOI: 10.1111/gcb.14481

49. Chen H, Liang Z, Liu Y, Jiang Q, Xie S. Effects of drought and flood on crop production in China across 1949–2015: spatial heterogeneity analysis with Bayesian hierarchical modeling. Natural Hazards. 2018;92:525–541.
DOI: 10.1007/s11069-018-3216-0
50. Yang Z, Zhang Z, Zhang T, Fahad S, Cui K, Nie L, et al. The effect of season-long temperature increases on rice cultivars grown in the central and southern regions of China. Front. Plant Sci. 2017;8:1908–1927.
DOI: 10.3389/fpls.2017.01908
51. Shah L, Ali A, Yahya M, Zhu Y, Wang S, Si H, et al. Integrated control of fusarium head blight and deoxynivalenol mycotoxin in wheat. Plant Pathol. 2018;67:532–548.
DOI: 10.1111/ppa.12785
52. Kheir AM, El Baroudy A, Aiad MA, Zoghdan MG, El-Aziz MAA, Ali MG, *et al*. Impacts of rising temperature, carbon dioxide concentration and sea level on wheat production in North Nile delta. Sci. Total Environ. 2019;651:3161–3173.
DOI: 10.1016/j.scitotenv.2018.10.209
53. Chun JA, Li S, Wang Q, Lee WS, Lee EJ, Horstmann N, et al. Assessing rice productivity and adaptation strategies for Southeast Asia under climate change through multi-scale crop modeling. Agric. Sys. 2016;143:14–21.
DOI: 10.1016/j.agsy.2015.12.001
54. Zafar SA, Hameed A, Nawaz M A, Wei MA, Noor MA, Hussain M. Mechanisms and molecular approaches for heat tolerance in rice (*Oryza sativa* L.) under climate change scenario. J. Integrative Agric. 2018;17: 726–738.
DOI: 10.1016/S2095-3119(17)61718-0.
55. Ahmed T, Scholz M, Faraj FA, Niaz W. Water-related impacts of climate change on agriculture and subsequently on public health: A review for generalists with particular reference to Pakistan. International Journal of Environmental Research and Public Health. 2016;13(11): 1051.
56. Wang B, Liu DL, Asseng S, Macadam I, Yu Q. Modeling wheat yield change under CO2 increase, heat and water stress in relation to plant available water capacity in eastern Australia. European Journal of Agronomy. 2017;90: 152-161.
57. Gouldson A, Colenbrander S, Sudmant A, Papargyropoulou E, Kerr N, McAnulla F, et al. Cities and climate change mitigation: economic opportunities and governance challenges in Asia. Cities; 2016;54:11–19.
DOI: 10.1016/j.cities.2015.10.010
58. Chow J, Khanom T, Hossain R, Khadim J. Forest management for climate change adaptation in Bangladesh. Confront. Climate Change Bangladesh. 2019;2:39–50.
DOI: 10.1007/978-3-030-05237-9_4
59. Degani E, Leigh SG, Barber HM, Jones HE, Lukac M, Sutton P, et al. Crop rotations in a climate change scenario: short-term effects of crop diversity on resilience and ecosystem service provision under drought. Agric. Ecosys. Environ. 2019;285:106625.
DOI: 10.1016/j.agee.2019.106625
60. Sanz-Cobena A, Lassaletta L, Aguilera E, Del Prado A, Garnier J, Billen G, et al. Strategies for greenhouse gas emissions mitigation in Mediterranean agriculture: a review. Agric. Ecosys. Environ. 2019;238: 5–24.
DOI: 10.1016/j.agee.2016.09.038
61. Suryadi FX. Soil and Water Management strategies for tidal lowlands in Indonesia. Boca Raton, FL: CRC Press; 2020.
DOI: 10.1201/9780429333231
62. Kole C, Muthamilarasan M, Henry R, Edwards D, Sharma R, Abberton M. et al. Application of genomics-assisted breeding for generation of climate resilient crops: Progress and prospects. Frontiers in Plant Science. 2015;6:563.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/109593